Chandra Observations of Two Pairs of Merging Early Galaxies

R. P. Kraft, G. Boué, W. R. Forman, C. Jones, S. S. Murray

Harvard/Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138

E. Churazov

Max-Planck-Institut für Astrophysik, Postfach 1317, 85741 Garching, Germany

A. Vikhlinin, M. Markevitch

Harvard/Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138

S. Heinz

Max-Planck-Institut für Astrophysik, Postfach 1317, 85741 Garching, Germany

ABSTRACT

We present preliminary results from Chandra/ACIS-I observations of two nearby pairs of merging early galaxies: NGC 3607/3608 and NGC 7619/7626. We have measured the temperatures, elemental abundances, and surface brightness profiles for each of the four galaxies. NGC 3607 is three times more luminous than NGC 3608 in the optical band, but the ratio of X-ray luminosity to optical luminosity is approximately the same in each. This is surprising because the gas temperatures are also the same ($\sim$0.6 keV). This indicates that while NGC 3607 contains three times the mass of gas and stars compared with NGC 3608, the depths of their gravitational potentials are similar. The second pair, NGC 7619/7626, is perhaps more interesting and unusual. The average gas temperature of both galaxies is $\sim$1.2 keV, but NGC 7619 is the more X-ray luminous of the two. There is a sharp surface brightness discontinuity in the emission from NGC 7619 in the direction of NGC 7626 and an extended X-ray tail in the opposite direction. This suggests that NGC 7619 is falling into NGC 7626 and that the mass of NGC 7626 is considerably larger than that of NGC 7619. This also implies that either a considerable fraction of gas around NGC 7626 escaped at some time in the past, or that the gas is not currently visible because it is contained in a hot, low density halo. We speculate that much of the gas around NGC 7626 was heated or expelled during an earlier epoch of radio activity.

Outline

1. Introduction

2. Two Pairs of Interacting Galaxies

- **We have measured the temperatures, abundances, radial surface brightness profiles, and gravitating mass profiles of four relatively isolated early-type galaxies. Both pairs show evidence of interaction.**

3. Surface Brightness Discontinuities (Cold Fronts, *Cool* Fronts, and Abundance Fronts)

- **We have detected a surface brightness discontinuity in the X-ray emission around NGC 7619 with a small temperature jump across the discontinuity.**

4. Summary and Conclusions

Galaxy Summary

Name	Distance (Tonry *et al.* 2001)	L_B
NGC 3607	**22.8 Mpc**	**10.59**
NGC 3608	**22.8 Mpc**	**10.24**
NGC 7619	**53.0 Mpc**	**10.82**
NGC 7626	**53.0 Mpc**	**10.80**
Other Galaxies		
NGC 507	**67 Mpc**	
NGC 1404	**19 Mpc**	
NGC 4472 (M 49)	**17 Mpc**	
NGC 5128 (Cen A)	**3.4 Mpc**	

Observation Log

Pair	Date	Obs. Time	Instrument
NGC 3607/08	**12JUN01**	**37.0 ks**	**ACIS-I**
NGC 7619/26	**20AUG01**	**26.7 ks**	**ACIS-I**

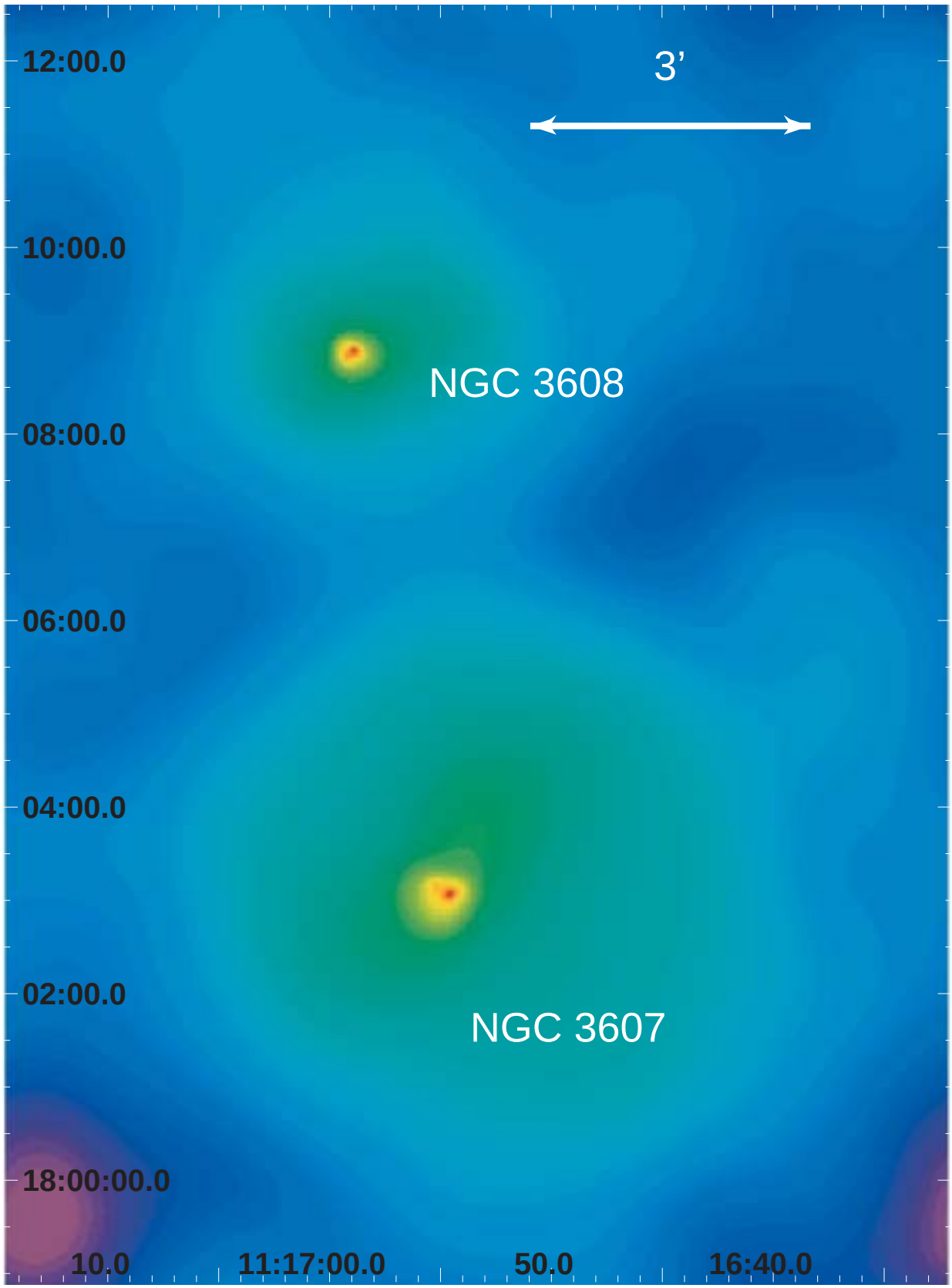

Fig. 1.— Adaptively smoothed, exposure corrected, background subtracted Chandra/ACIS-I image of the NGC 3607/3608 pair of galaxies in the 0.5-2 keV band.

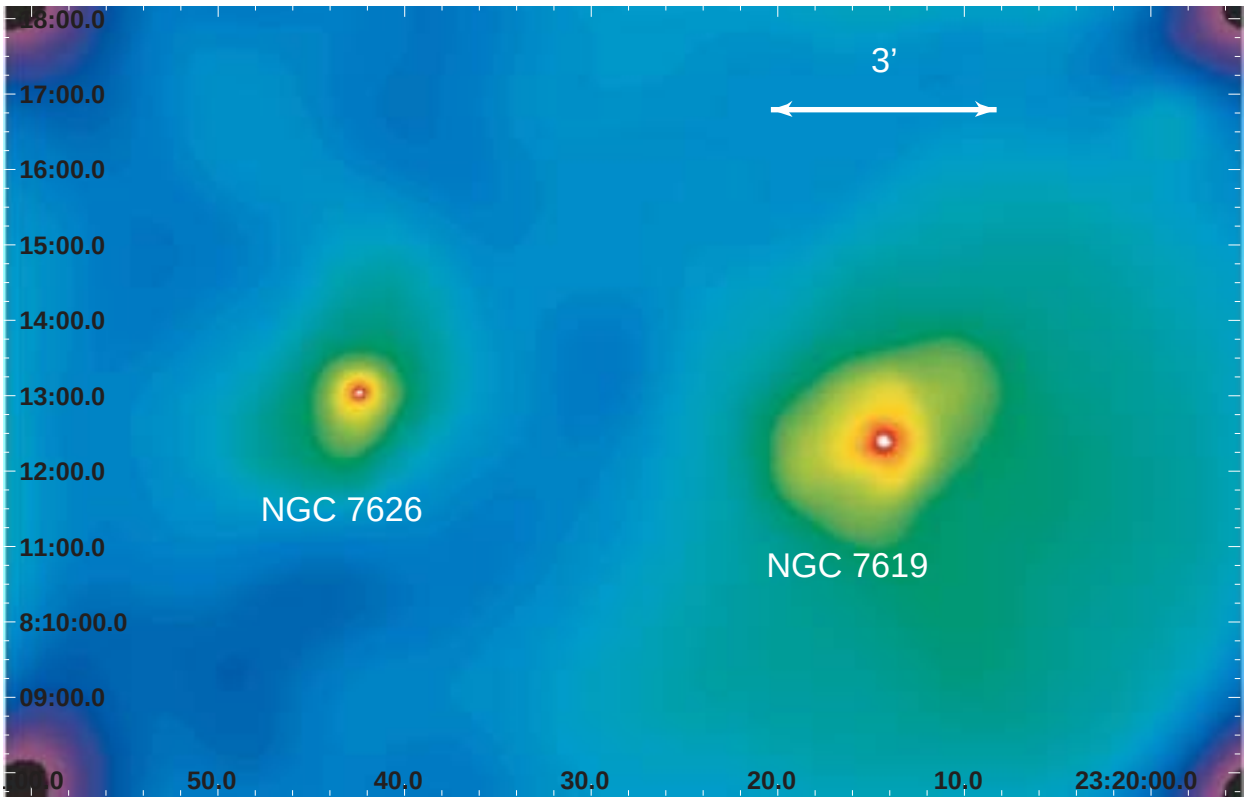

Fig. 2.— Adaptively smoothed, exposure corrected, background subtracted Chandra/ACIS-I image of the NGC 7619/7626 pair of galaxies in the 0.5-2 keV band.

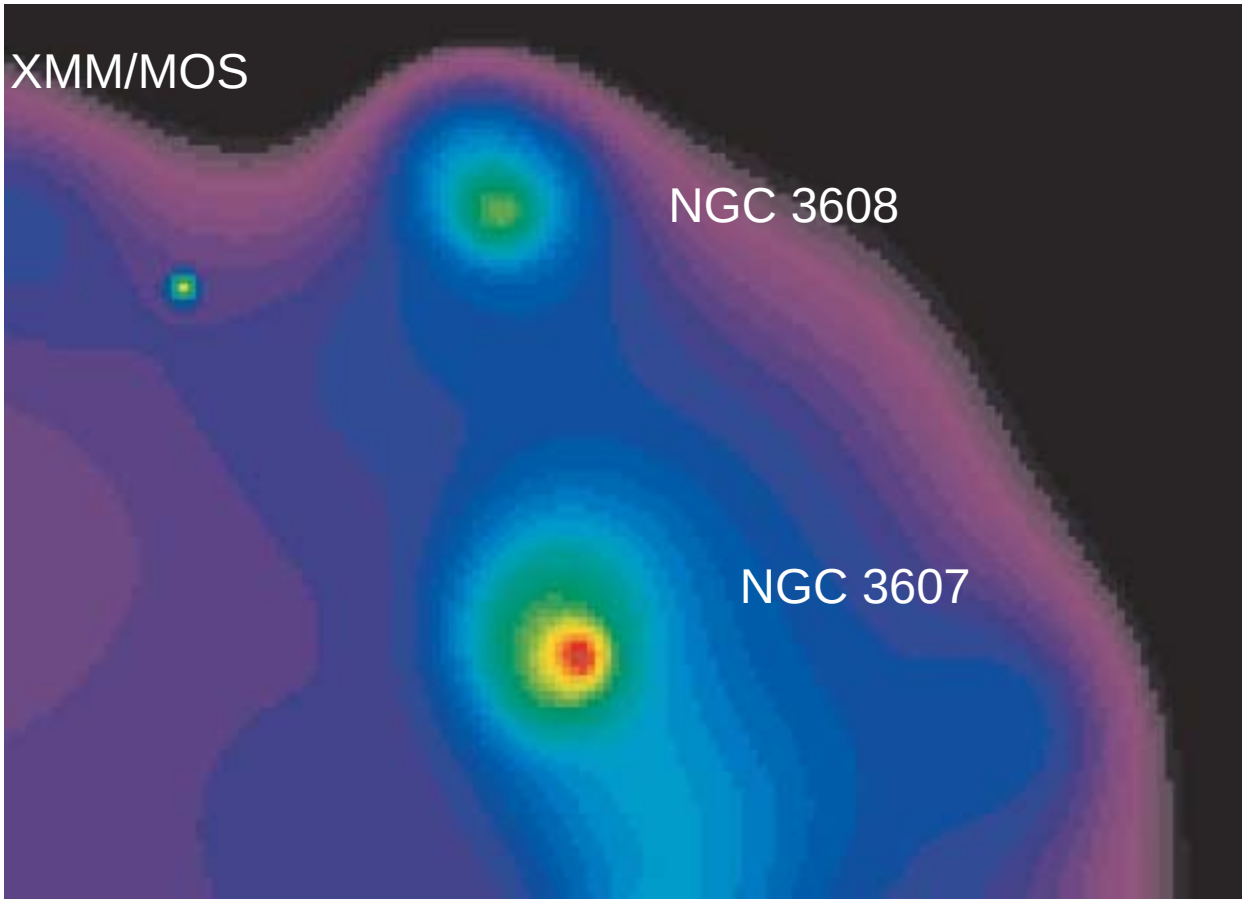

Fig. 3.— Adaptively smoothed XMM/MOS image of the NGC 3607/3608 pair of galaxies in the 0.5-2 keV band.

ANALYSIS SUMMARY - β-MODEL PARAMETERS

Name	$\log(L_X)$	L_B	β	r_c	$< T >$
NGC 3607	**40.27**	**10.59**	**0.45**	**6.5 kpc**	**0.65 keV**
NGC 3608	**39.87**	**10.24**	**0.50**	**3.0 kpc**	**0.6 keV**
NGC 7619	**41.69**	**10.82**	**0.47**	**6.0 kpc**	**0.9-1.2 keV**
NGC 7626	**41.00**	**10.80**	**0.72**	**8.5 kpc**	**0.9-1.2 keV**

- **The elemental abundance is generally between 0.2-0.4 times Solar, with some evidence of a gradient (increasing) toward the center.**
- **For the NGC 3607/3608 pair, the ratio of the X-ray to optical luminosities are similar. However, the temperature of the gas in the two galaxies is similar, which indicates that the depth of the gravitational potentials is similar.**
- **For the NGC 7619/7626 pair, the optical luminosities and gas temperatures are similar, but there is a large difference in their X-ray luminosities.**
- **ROSAT detected a tidal tail behind NGC 7619 (Trinchieri *et al.*, 1997), and XMM/Newton observations suggest a similar tail behind NGC 3607. In both cases, it appears that the more X-ray luminous object is falling into the X-ray fainter object.**

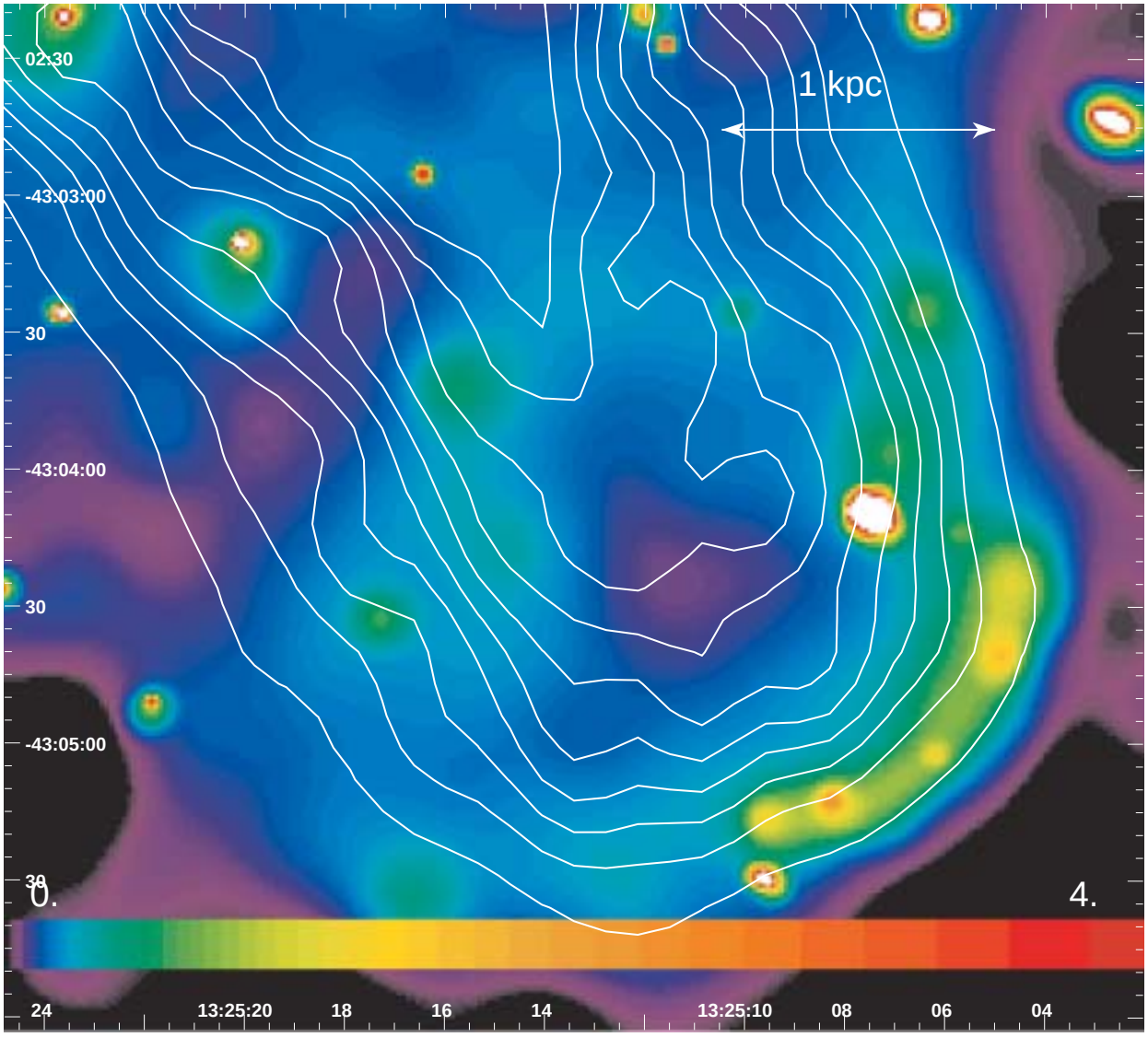

Fig. 4.— Adaptively smoothed, exposure corrected, background subtracted Chandra/ACIS-I image of the SW radio lobe of Centaurus A in the 0.5-2 keV band with 13 cm radio (ACTA) contours overlaid.

SURFACE BRIGHTNESS DISCONTINUITIES AND *COOL* FRONTS

- **We have detected a large surface brightness discontinuity in NGC 7619 with a relatively small temperature gradient.**
- **Such fronts have now been observed in a number of cluster mergers and galaxy mergers (e.g. NGC 1404 and NGC 4472).**
- **The size of the discontinuity NGC 7619 cannot be understood in terms of the simple 'cold-front' model. That is, the jump is too large for the small temperature difference.**
- **A similar problem was noticed in NGC 507 (although this discontinuity is probably jet driven). One possible explanation for this is an 'abundance' front, although the data does not support this hypothesis in NGC 7619.**

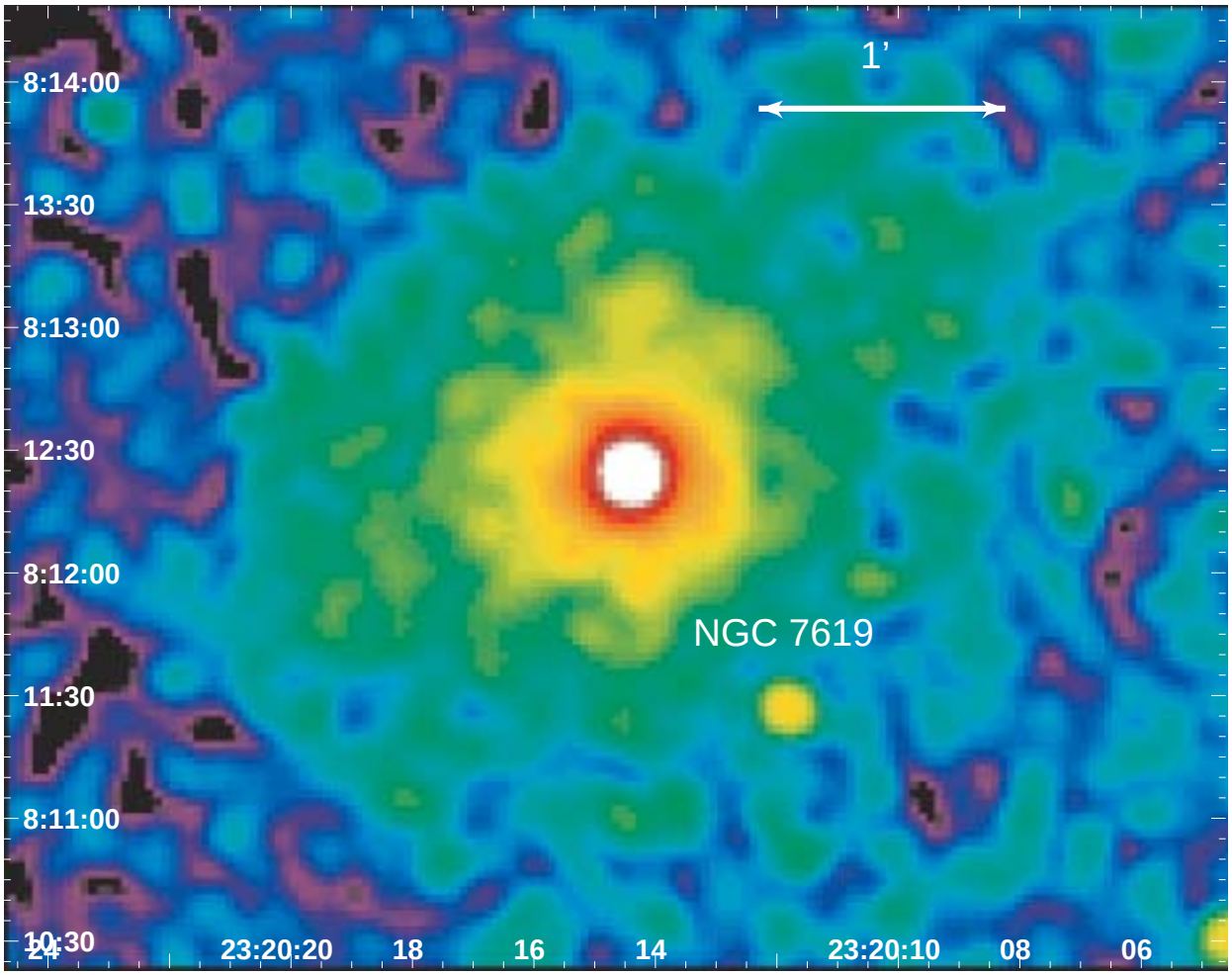

Fig. 5.— Gaussian smoothed (σ=2″) Chandra/ACIS-I image of the surface brightness discontinuity in NGC 7619 in the 0.5-2 keV band.

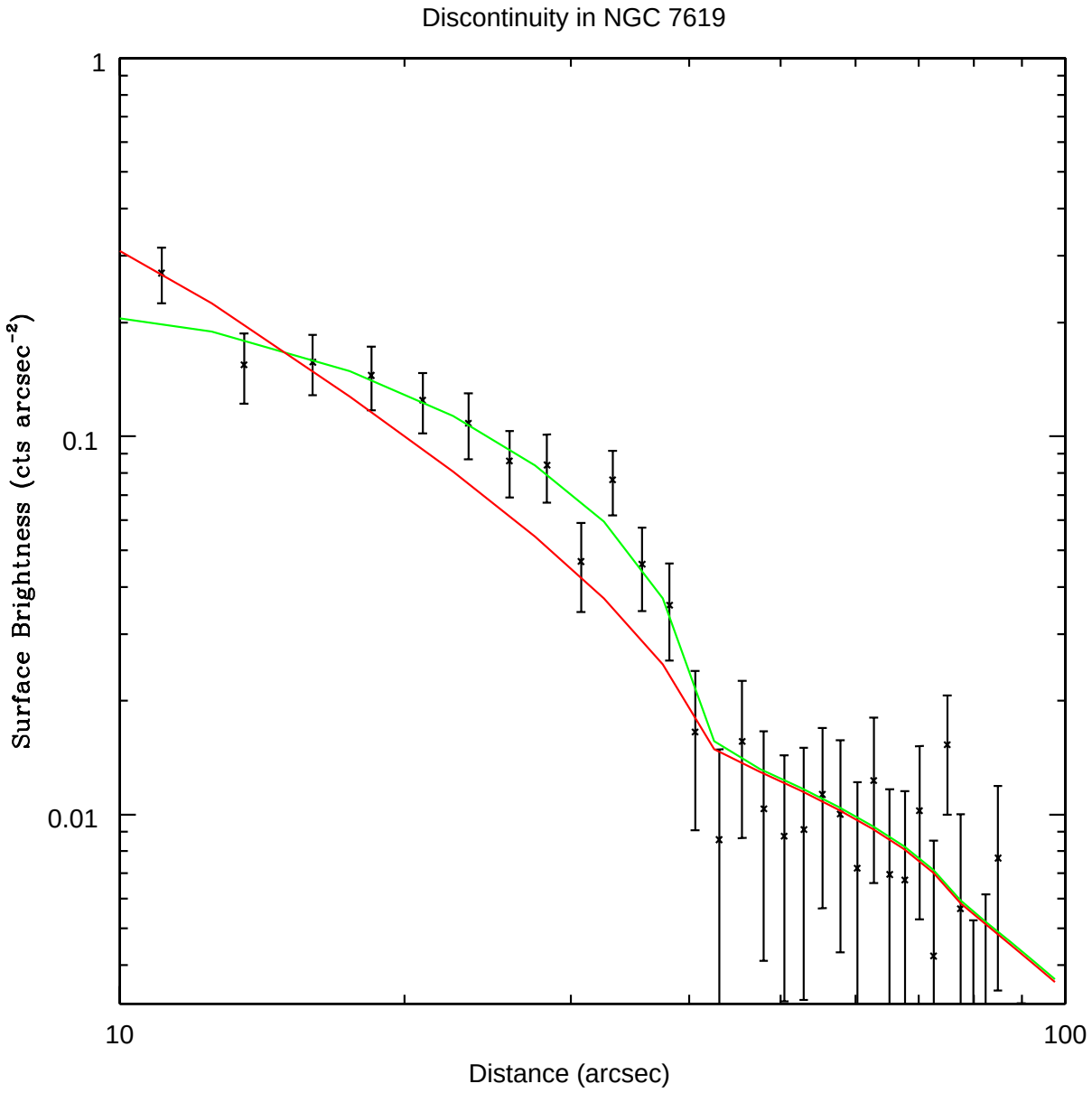

Fig. 6.— Surface brightness profile in a 70° sector along the surface brightness discontinuity in NGC 7619. The red curve represents the modeled profile based on the small (∼20%) difference in temperature across the interface. The green curve represents a larger (∼50%) jump in density (and pressure) to match the discontinuity. This second model implies a pressure discontinuity.

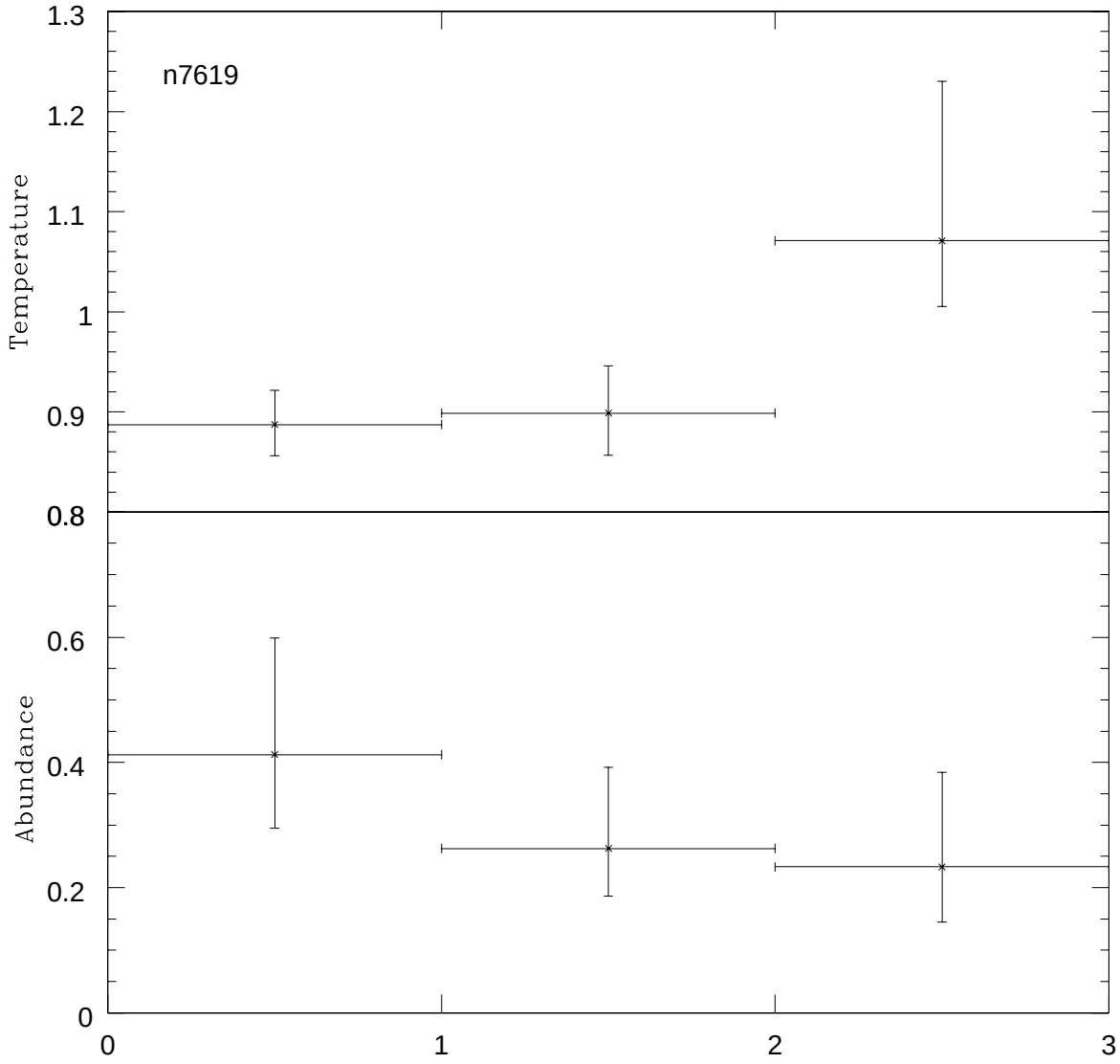

Fig. 7.— Best fit temperatures and elemental abundances (relative to Solar) for three regions of NGC 7619. The first region is the central region around the nucleus, the send is interior to the discontinuity, and the third is the region beyond the discontinuity.

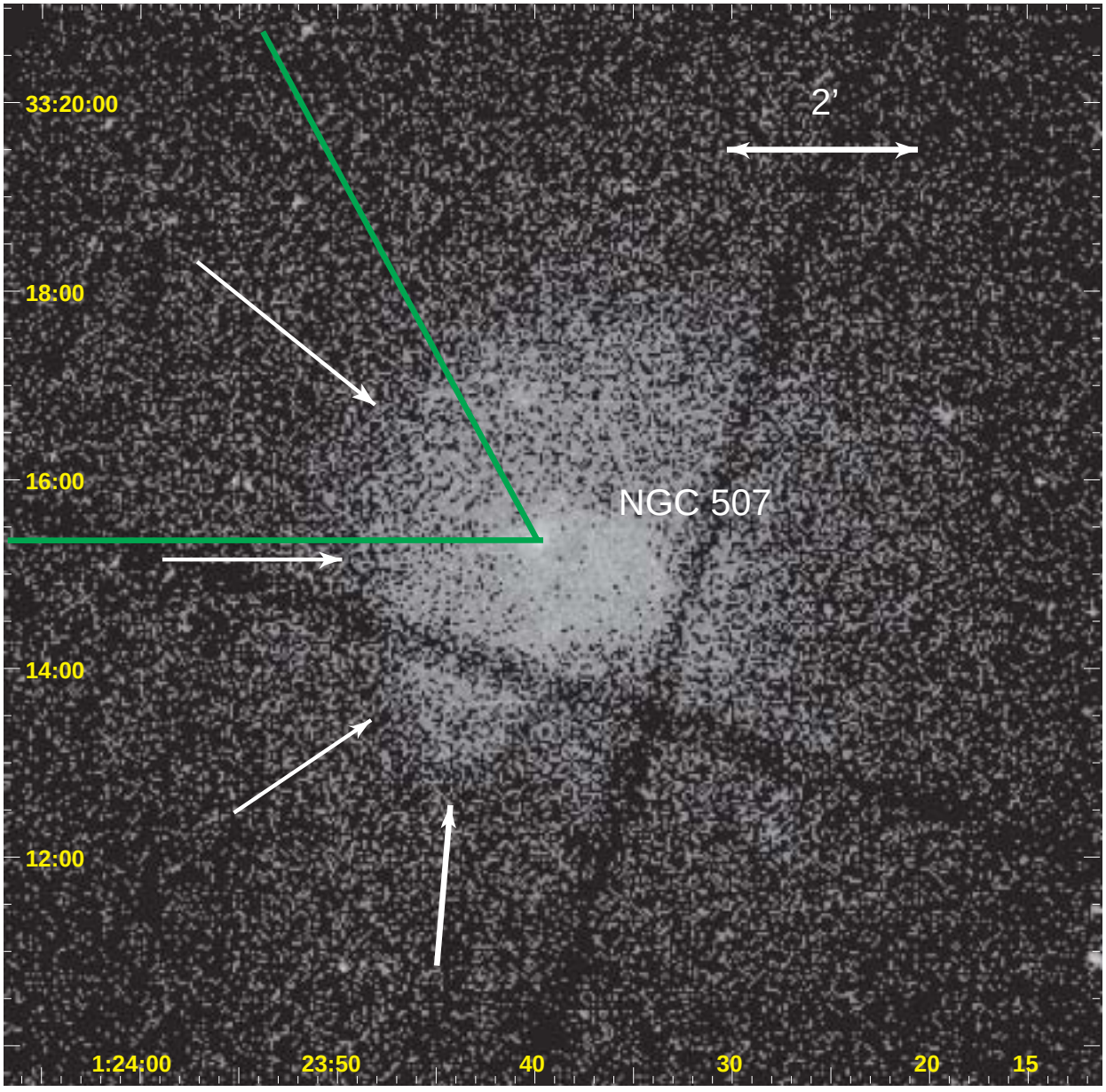

Fig. 8.— Raw Chandra/ACIS-I image of NGC 507 showing sharp surface brightness discontinuity.

Possible Explanations

- **Geometry**
- **The 'Steady Flow' approximation is almost certainly violated for NGC 507, and probably for NGC 7619 as well.**
- **Hydrostatic Equilibrium**
- **Ram Stripping/Cold Front Simulations of cold fronts in clusters (Heinz *et al.*, 2003) suggest transport of low entropy material in the center toward the contact discontinuity.**

The size of the ram-pressure stripped core of NGC 7619 suggests transonic ($M \sim 1$) infall. The lack of shock-heated gas sets the upper limit to the infall velocity at $M \leq 1.5$

SUMMARY AND CONCLUSIONS

- **We have measured the gas temperatures, densities, elemental abundances, and gravitating mass within ∼50 kpc of the nucleus of two pairs of merging early galaxies.**

  1. **In the NGC 3607/3608 pair, the ratio of the X-ray luminosities is similar to the ratio of the optical luminosities, and the temperatures are similar. This suggests that while the mass of stars and gas in NGC 3608 is less than NGC 3607, the depth of the gravitational potentials is similar.**
  2. **In the NGC 7619/7626 pair, the optical luminosities are similar, but NGC 7619 is several times brighter in X-rays than NGC 7626, while NGC 7626 may be several times more massive(?) as it appears that NGC 7619 is falling in towards it. Are there any massive, but optically and X-ray faint (but hot), objects that have blown all of their gas off? This result could support the idea that there is a cyclical relationship between the hot gas, cooling flows, and AGN/radio activity.**

- **We have detected a surface brightness discontinuity in NGC 7619 with a small temperature difference across the boundary. The size of this discontinuity cannot be simply explained by the 'cold-front' model commonly invoked in cluster mergers.**

- **NGC 3607 and NGC 7619 exhibit tidal tails indicative of ram-pressure stripping. Is NGC 3607 falling into NGC 3608?**

- **Chandra and XMM/Newton have given both observers and theorists lots of new problems to ponder related to the hydrodynamics of galaxy mergers, cold fronts, and radio lobe/IGM interactions.**